International Journal of Electrical and
Electronics Engineering Research (IJEEER)
ISSN(P): 2250-155X; ISSN(E): 2278-943X
Vol. 4, Issue 3, Jun 2014, 35-42

TRANS STELLAR
• Journal Publications • Research Consultancy

DESIGN OF NOVEL AXIAL FLUX PERMANENT MAGNET GENERATOR (AFPMG) FOR WIND ENERGY APPLICATION

ABID HUSAIN SAIFEE[1] & ARVIND MITTAL[2]

[1]Vice-Principal, All Saints' College of Technology, Bhopal, India

[2]Associate Professor, Department of Energy, Maulana Azad National Institute of Technology, Bhopal, India

ABSTRACT

This paper presents a novel design of axial flux permanent magnet generator using torus construction of stator with plastic material for wind energy generation system. In this Generator the stator is sandwiched between rotor discs where north pole of one rotor disc faces south pole of opposite rotor disc. In this arrangement as the flux does not pass radial in the stator disc, hence does not require magnetic material. This in turn means no iron losses in the designed machine. Designs were prepared for various ratings with same value of design parameters and comparison was made between Axial Flux Permanent Magnet Generator (AFPMG) and Radial Flux Permanent Magnet Generator (RFPM).

KEYWORDS: Axial Flux Permanent Magnet Generator, Radial Flux Permanent Magnet Generator, Plastic Material Stator, Design, FORTRAN-77

INTRODUCTION

In last one decade axial flux machine has become popular. Popularity of axial flux permanent magnet generators are mainly because lesser use of structural materials, distributed load on shaft and no field losses. Wind mill has a typical application where speed and power is not constant hence generates variable power with variable voltage and frequency. For utilization of the wind power, it has to be stored in battery for which AC-DC converter and DC-DC converter is must. In case of AC output utilization after DC-DC Converter, DC-AC Inverter will also be required. The rating of DC-DC converter & DC-AC inverter need to be designed for maximum power and voltage.

Principle of Operation

Conventional Radial Flux Permanent Magnet Generator (RFPMG) comprises of Stator which is static and is of hollow cylinder construction houses winding, stampings to hold the winding and a frame. The rotor is a rotating part of machine which is also of cylindrical design and houses permanent magnet poles, core for housing the poles and also for providing path for magnetic flux, cooling fan and shaft.

General layout arrangement of RFPMG [2] is shown below in Figure 1. In RFPMG there is an air gap between stator and rotor and is measured radial. Magnetic flux through air gap passes radial and through stator and rotor both radial and peripheral hence it is called RFPMG. Further in RFPMG active part of winding is axial i.e. parallel to the axis of rotation and ineffective / overhang part of winding in peripheral.

Basic design equation for RFPMG known as output equation is given below:

$$P = \mathrm{Co} \times D^2 \times \mathrm{L} \times \mathrm{N_s} \tag{1}$$

$$Co = 11.1 \times Bg \times A \times C \times Cos\emptyset \times \eta \tag{2}$$

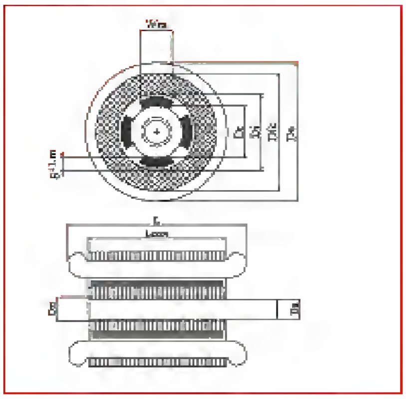

Figure 1: General Layout of RFPMG

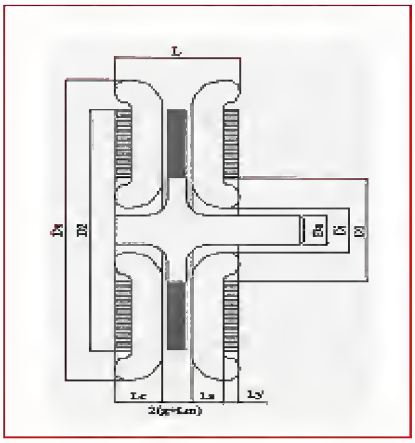

Figure 2: General Arrangement of AFPMG

Axial Flux Permanent Magnet Generator (AFPMG) also basically comprises of Stator which is a stationary part of machine and in the form of disc houses winding & frame and rotor which is a rotating part houses permanent magnet and end plate for holding the magnets and path for magnetic flux. Shaft is also a part of rotor. Stator and rotor are separated by an air gap which is measured axially. Magnetic flux in the air gap passes axially hence termed as AFPMG. Active part of winding is radial and ineffective part /overhang is peripheral in AFPMG. The general arrangement of AFPMG [2] is shown in Figure 2.

Sizing equation which is derived from basic **Blv** is given as follow:

$$P = \frac{\pi^2}{8} \times Bg \times AC \times D^3 \times (1\text{-}k^2) \times (1+k) \times N_s \times Cos\ (\varphi) \times \eta \times N_{stage} \tag{3}$$

Where,

P = Power output

Bg = Air gap Flux Density

AC = Amp. Cond / Stator Periphery

D = OD of Stator

k = ID / OD Stator

Ns = RPS of M/c

Cos (φ) = Power Factor

η = Efficiency

N_{stage} = Number of Stator Stages.

Using the same value of Bg, AC, η and Cos (φ) designs were prepared for RFPMG and AFPMG.

Axial Flux PM Generator

Various combinations are possible in AFPMG based on arrangement of rotating and static discs. Various such configurations of AFPMG are discussed herein.

One Disc of Rotor and One Disc of Stator as Shown in Figure 3 Below

In this arrangement end plate / disc of rotor and stator both will require magnetic material. In this design machine will have both copper and iron loss factor and is not much different from RFPMG.

Rotor Sandwiched between Stator Discs as Shown in Figure 4

In this design since one rotor disc with PM is sandwiched between two stator discs and rotates between them. Stator will have end plates which act as a return path for magnetic flux. As rotor rotates, flux through stator end plate varies with time and will cause iron losses. Winding will generate copper loss. This configuration will also not different from RFPMG.

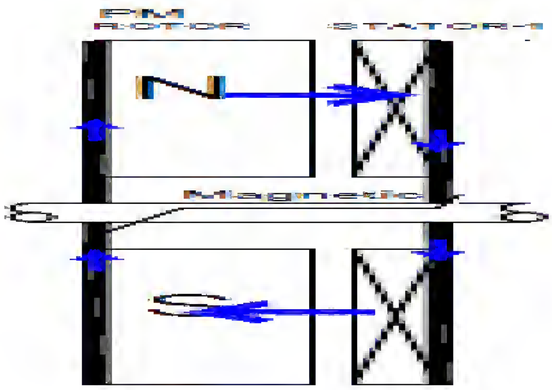

Figure 3: Stator and Rotor One Disc Each

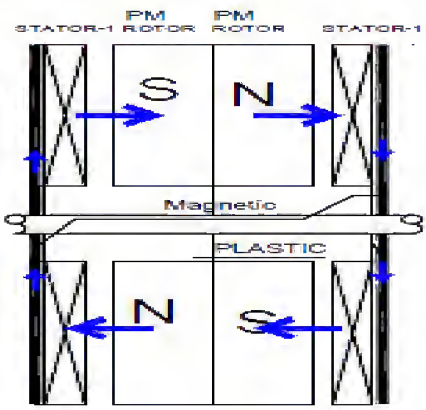

Figure 4: Rotor Sandwiched between Stator

Stator Sandwiched between Rotors

It can further have 2 different arrangements.

Stator sandwiched between rotors and north poles on one rotor disc faces North Pole on opposite rotor disc as shown in Figure 5.

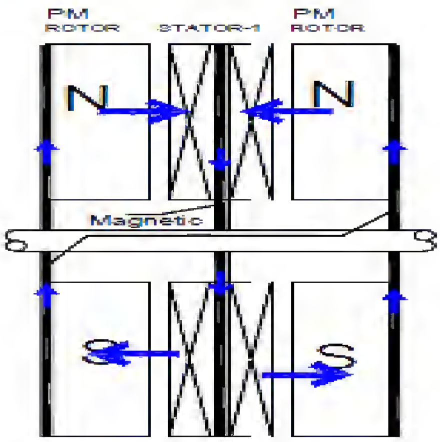

Figure 5: Stator Sandwiched between Rotor NN-SS Arrangement

In this design as clear from layout that stator plate which houses coil act as return path for magnetic flux and will require being of magnetic material. In any case rotor end plate will also be of magnetic material to supply return path for magnetic flux. Again the flux in stator end plate will vary with time and will generate iron losses and copper loss component because of winding. This configuration also is not of much interest for high efficiency wind applications.

Stator sandwiched between rotor discs where north pole of one rotor disc faces south pole of opposite rotor disc [3] as shown in Figure 6.

In this arrangement since the flux does not pass radial in the stator disc and does not require magnetic material, hence no iron losses in the machine.

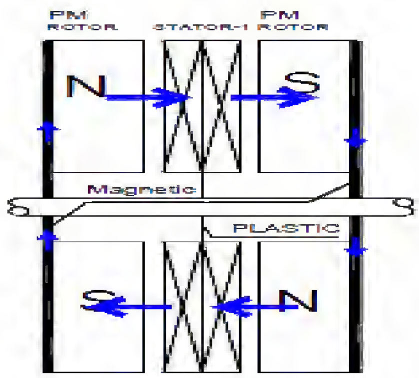

Figure 6: Stator Sandwiched between Rotor NS-SN Arrangements

Considering these configurations of stator and rotor configuration of Figure 6 was selected because stator does not contain iron parts which avoid magnetic losses and will lead to better efficiency. Since, stator does not require magnetic path and also is stationery so plastic material will be suitable for housing stator winding. It will have two advantages:

- Low stator weight most suitable for wind application.
- No additional insulation other than copper self insulation.

Design of Axial Flux PM Generator

Considering the configuration as given in Figure 6, software was developed in FORTRAN-77 based on basic equations discussed earlier and conventional design procedure. Various ratings from 500 watts upto 5000 watts in steps of 500 Watts were designed for both RFPMG and AFPMG with the same values of Bg (0.6 Wb/m^2), AC (15000AC/m-30000AC/m for 500W-5000W respectively) and current density J(4.0A/mm^2-5.0A/mm^2 for 500W- 5000W respectively). The input data of 2000 Watts AFPMG for single stage and ID/OD ratio of 0.1 is given below in Table 1.

Table 1: Input Data for 2000 WATTS AFPMG Stages=1 ID/OD=0.1

Parameters	Value	Units	Parameters	Value	Units
B_{av}	0.60	Wb/m^2	STF	0.950	Factor
AC	20000.0	AC/m	SPPH	1.00	Nos
DTOL	1.40	Ratio	J	4.3333	A/mm^2
GAIRM	1.00	mm	BMCR	1.50	Wb/m^2
PARC	0.70	Ratio	CUDEN	8.90	G/CC
HPRM	12.50	mm	FEDEN	7.80	G/CC
OUTPUT	2000.0	W	SHEER	840.0	Kg/Cm^2
POLE	10.0	Nos	TENSI	1400.0	Kg/Cm^2
PH.VOLTS	240.0	V	RCU	600.0	Rs/Kg
EFF	0.80	%	RFE	200.0	Rs/Kg
PF	0.70	Factor	RP	2000.0	Rs/Kg
NS	5.00	RPS	RFES	400.0	Rs/Kg
FACTW	0.950	Factor	RSFT	300.0	Rs/Kg
SF	0.60	Factor	FREQ	25.0	Hz

The mechanical design parameters for the above machine as calculated are tabulated in Table 2. The electrical design parameters (along with losses and efficiency), costing details and performance index are compiled in Table 3.

Table 2: Mechanical Design Parameters

Parameters	Value	Units	Parameters	Value	Units
Stator			Rotor		
OD	360.00	mm	OD	360.00	mm
ID	40.00	mm	ID	40.00	mm
Pole Length	160.00	mm	LENGTH	85.1327	mm
SLOTS	30.00	Nos	WPOLEOD	79.1682	mm
HCOILB	29.7969	mm	WPOLEID	8.7965	mm
WCOILT	37.6991	mm	HPR	12.50	mm
AVCOILW	20.9440	mm	ODRC	40.00	mm
ODFR	386.00	mm	POLES	10.00	Nos
LFR	85.1327	mm	EPTHKR	12.5664	mm
TEP	5.00	mm	ODEPR	360.00	mm
ODEP	360.00	mm	WTEP	19.8861	Kg
IDEP	21.00	mm	LSHAFT	235.1328	mm

Table 3: Electrical and Performance Parameters

Parameters	Value	Units	Parameters	Value	Units
Elect. Design			Costing		
CUGAUGE	18.0000	SWG	COSTFE	7582.8281	Rs
TPH	420.0000	No	COSTCUS	4127.5342	Rs

Table 3: Contd.,

LMT	0.5257	m	COSTSFT	182.4665	Rs
RPH20S	3.2767	Ohms	COSTPMR	27444.9590	Rs
RPH75S	4.2597	Ohms	COSTT	39337.7891	Rs
LD	0.2521	H	PERFORMANCE INDEX		
LQ	0.0500	H	WTT	59.1241	Kg
LOSSSCUS	314.4256	W	COSTPKW	19668.8965	Rs/KW
EFF	86.4145	%	WTPKW	29.5620	Kg/KW
			ENERGY COST	330750.6250	Rs

Comparison of RFPMG & AFPMG

Designs were carried out for 500 watts to 5000 watts of both RFPMG and AFPMG with configuration as shown in Figure 6 using the same values of Bg, AC and current density J. It is observed that throughout the range AFPMG efficiency is much higher as compared to RFPMG. Figure 7 shows the efficiency of AFPMG and RFPMG for all the range under consideration in the form of Bar Graph while Figure 8 shows the energy saving in terms of rupees based on 15 years of operation of AFPMG (assuming 16 hours per day working 25 days a month).

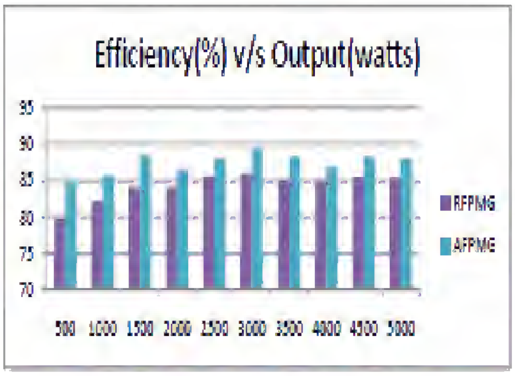

Figure 7: Efficiency Chart

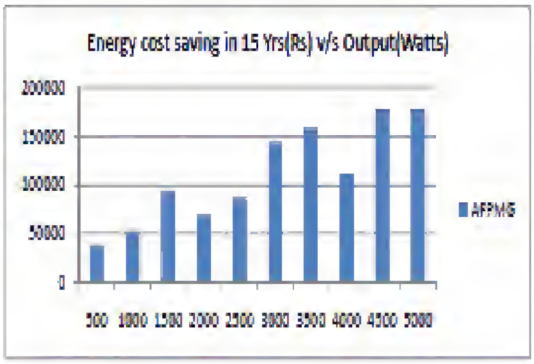

Figure 8: Energy Saving

These designs involve double rotor arrangement hence these requires double number of permanent magnets as compared to single rotor design of RFPMG. Permanent magnets are the costliest item in these machines, hence the cost and weights of active material of AFPMG is more compared to RFPMG. Comparative charts of cost and weights are shown in Figure 9 & 10.

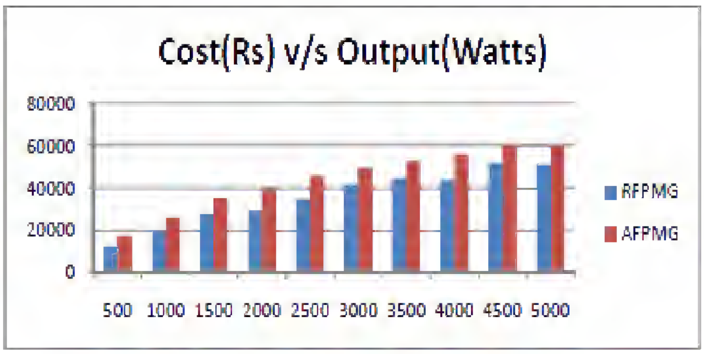

Figure 9: Cost of Active Material

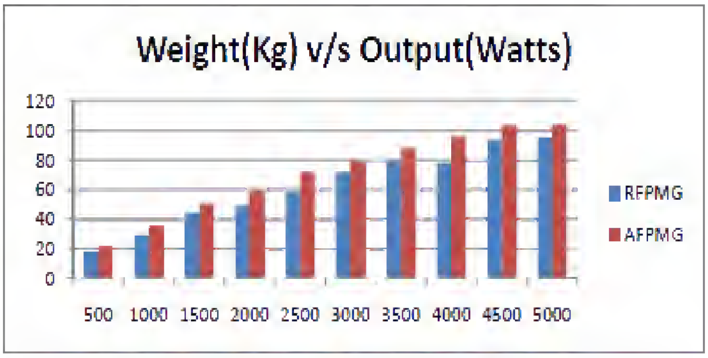

Figure 10: Weight of Active Material

Based on these comparative charts of cost and weight it looks at first sight that RFPMG is better than AFPMG. But, in final cost comparison considering cost of energy saved because of high efficiency and the differential cost as financial benefit, it is further observed that considering all these factors AFPMG is cheaper and in 15 years machine pays off its cost. Net savings in case of AFPMG is shown in Figure 11. Further it is also observed that weight difference is marginal.

Since, rotor diameter in case of AFPMG is more than that of RFPMG, it will produce high inertia machine. As far as electrical performance is concerned AFPMG has lower values of X_d & X_q as compared to RFPMG.

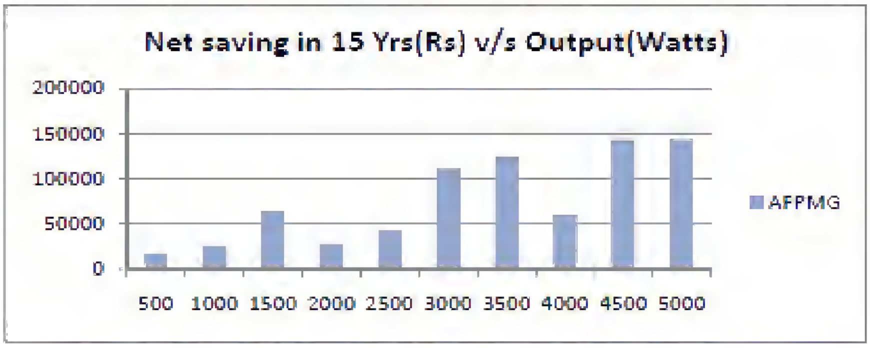

Figure 11: Net Saving

CONCLUSIONS

Based on comparative study it is concluded that efficiency of AFPMG is better than RFPMG. In spite of high cost and weight of AFPMG, it proves to be economical on long run and more suited for wind applications. As, AFPMG machine has lower value of X_d & X_q it has better regulation and stability. AFPMG will be much cooler as compared to RFPMG. Also the insulation cost is much less in AFPMG as there is no metal in the stator. AFPMG with stator sandwiched between two rotor in NS-SN arrangement stator may be of plastic material and slot-less will be quite and no harmonic torques [4] [5] [7].

ACKNOWLEDGEMENTS

Authors would like to thank Maulana Azad National Institute of Technology, Bhopal & ASCT, Bhopal for encouragement and their constant support.

REFERENCES

1. P. Campbell, "Principles of a permanent-magnet axial-field DC machine", *Proc. IEE*, Vol. 121, Dec. 1974, pp.1489-1494.
2. Andrea Cavagnino, Mario Lazzari, Francesco Profumo, *Senior Member, IEEE*, and Alberto Tenconi, *Member, IEEE* "A Comparison Between the Axial Flux and the Radial Flux Structures for PM Synchronous Motors" IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 38, NO. 6, NOVEMBER/DECEMBER 2002 1517
3. C. C. Jensen, F. Profumo and T. A. Lipo, "A low loss permanent magnet brushless DC motor utilizing tape wound amorphous iron", *IEEE Trans. on Industry Applications*, Vol. 28, No. 3, May/June 1992, pp.646-651.
4. T. A. Lipo, S Huang and M. Aydin, "Performance assessment of axial flux permanent magnet motors for low noise applications", *Final Report to ONR*, Oct 2000.
5. S. Huang, M. Aydin and T. A. Lipo, "Low noise and smooth torque permanent magnet propulsion motors: Comparison of non-slotted and slotted radial and axial flux topologies", *IEEE International Aegean Electrical Machine and Power Electronic Conference*, Kusadasi-Turkey, 2001, pp.1-8.
6. S. Huang, M. Aydin and T. A. Lipo, "TORUS concept machines: preprototyping design assessment for two major topologies", *IEEE Industry Applications Society Annual Meeting*, Chicago, 2001.
7. M. Aydin, S. Huang and T. A. Lipo, "Design and electromagnetic field Analysis of non-slotted and slotted TORUS type axial flux surface mounted disc machines", *IEEE International Conference on Electrical Machines and Drives*, Boston, 2001, pp.645-651.
8. S. Huang, J. Luo, F. Leonardi, and T. A. Lipo, "A general approach to sizing and power density equations for comparison of electrical machines," *IEEE Trans. on Industry Applications*, IA-34, No.1, pp.92-97, 1998.
9. S. Huang, J. Luo, F. Leonardi and T. A. Lipo, "A comparison of power density for axial flux machines based on the general purpose sizing equation", *IEEE Trans. on Energy Conversion*, Vol.14, No.2 June 1999, pp.185-192.
10. Y. Li and T. A. Lipo, "A doubly salient permanent magnet motor capable of field weakening", *IEEE Power Electronics Specialists Conference*, 1995; pp.565-571.
11. F. Profumo, A. Tenconi, Z. Zhang and A. Cavagnino, "Novel axial flux interior PM synchronous motor with powdered soft magnetic material", *IEEE Industry Applications Society Annual Meeting*, 1998, pp.152-158.